

REMARKS

This Preliminary Amendment is being filed in order to incorporate specification and claim amendments reflected in the annexes to the International Preliminary Examination Report into the present U.S. national stage application, to improve the form of the specification and abstract, and to place the claims of this U.S. national stage application into a form which is more appropriate for examination in the United States.

A marked-up version of the substitute specification, showing matter added to the translation by underlining and matter deleted from the translation between brackets, is attached to the Preliminary Amendment as Appendix III. The substitute specification is believed to contain no new matter.

Respectfully submitted,

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5 [Process for producing a catalytic converter] PROCESS
FOR PRODUCING A CATALYTIC CONVERTER

BACKGROUND OF THE INVENTION

10 The present invention relates to a process for producing a catalytic converter.

15 [The disclosure JP-A-] Japanese patent publication JP A 08 134 682 [has described] describes an electroplating process for coating a metallic substrate with a smooth precious metal layer, in which an iron-containing substrate is provided with a platinum covering. [The] German patent DE 197 32 170 C2 [has disclosed] discloses a process for covering a ceramic 20 SiC substrate in a locally selective manner with a platinum covering, the surface of which matches the rough ceramic surface, as a result of a direct voltage being applied between the substrate and a counterelectrode. The coated substrate is then treated 25 at elevated temperature of over 400°C.

30 European publication EP-A-106 197 discloses a process which forms a starting point for the invention and provides for electrochemical deposition of a porous platinum layer. The layer is deposited on a carbon or semiconductor substrate. In this process, a one-off high voltage pulse is applied between a substrate and a counterelectrode so that nuclei are deposited on the substrate. There then follows a prolonged pulse at a lower 35 voltage, during which growth of the nuclei takes place. U.S. Patent 4,273,624 discloses an electroplating process in which a thin, continuous layer of platinum is deposited on an SnO₂ substrate. Japanese patent publication JP A 7 80327 discloses a catalytic converter in which a metallic

substrate is coated with a thin, non-porous layer of precious metal. A lack of pores distinguishes the catalytic converter by a high resistance to oxygen.

5 SUMMARY OF THE INVENTION

[The] One object of the present invention is to provide a process for coating a metallic substrate which allows [the] deposition of a precious metal with 10 a large surface area and good adhesion to a substrate.

[This object is achieved by the features of the independent claim.]

15 According to the invention, a layer of catalytically active metallic material is deposited on a metal substrate by [means] way of electrochemical deposition[, the]. The substrate [being] is immersed in an electrolyte which contains the catalytically 20 active metallic material, and voltage [being] is applied between the substrate and a counterelectrode[, an]. An electric direct voltage on which an alternating voltage is superimposed [being] is applied between the substrate and the counterelectrode, and the 25 catalytically active material [being] is deposited on the substrate as a porous or non-cohesive layer.

It is particularly advantageous for the substrate to be provided, on its surface which is to be coated, 30 with a predetermined surface roughness prior to the deposition[, the]. The surface roughness preferably [lying] lies in the range from 0.3 μm to 10 μm . A [further preferred] more preferable range for the surface roughness is between 0.3 μm and 3 μm . The 35 surface roughness is expediently generated by thermal and/or mechanical and/or chemical treatment.

The catalytically active material is preferably formed from metal clusters with [a diameter of]

diameters between 2 nm and 1 μm , and preferably between 2 nm and 300 nm.

[The] One particular advantage of the process is 5 that it is possible to deposit catalytically active layers with a very large surface area and a relatively low level of catalytically active material. The layers exhibit good adhesion and are stable at high temperatures even after prolonged use.

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Preferred catalytically active materials are precious metals. One suitable catalytically active material is platinum. A preferred counterelectrode is formed by platinum-coated titanium sheet. A further 15 preferred counterelectrode consists of platinum-coated nickel.

In a particularly preferred refinement of the invention, platinum is deposited with different 20 morphologies. This provides catalytic converters which have different selectivities for conversion of matter. For example, it is possible to produce a preferred platinum catalytic converter for a reforming reactor which, despite a high carbon monoxide concentration in 25 an H₂/CO mixture, has a continuously high activity for hydrogen conversion in operation.

Further advantages and configurations of the invention will [emerge] be apparent from the [further] 30 claims and the description. The invention is described in more detail below with reference to [a] drawing[, in which:] figures.

BRIEF DESCRIPTION OF THE DRAWINGS

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Figure 1 [shows an outline] is a schematic view of a structure for carrying out the process according to the invention,

Figure 2 diagrammatically depicts a section through a coated surface,

5 Figures [3a, b] 3a-3c show [two] scanning-electron microscope images of the surface of a catalytic converter with dendritic platinum clusters,

10 Figure 4 shows a scanning-electron microscope image of the surface of a catalytic converter with spherical platinum clusters,

15 Figures [5a, b] 5a and 5b show two scanning-electron microscope images of the surface of a catalytic converter with dendritic platinum clusters before (Figure 5a) and after (Figure 5b) a long-term test,

20 Figures [6a, b] 6a and 6b show a comparison of rough (Figure 6a) and smooth (Figure 6b) surface profiles of steel substrates prior to the coating with catalyst material,

25 Figure 7 shows a measurement curve indicating the hydrogen conversion achieved by a catalytic converter with spherical platinum clusters in a CO-containing atmosphere, and

30 Figure 8 shows a measurement curve illustrating the conversion of hydrogen achieved by a catalytic converter with dendritic platinum clusters in a CO-containing atmosphere.

DETAILED DESCRIPTION OF THE INVENTION

35 Figure 1 shows an arrangement for carrying out the process according to the invention. A function generator 1 generates a modulated voltage which is amplified in an amplifier 2 and is applied between an anode 3 and a substrate 4 which is to be coated in a

deposition bath 5. A direct voltage V_{dc} is preferably superimposed with an alternating voltage V_{ac} . The sum voltage of direct voltage V_{dc} and alternating voltage V_{ac} is also referred to below as the modulated voltage 5 V_m . The alternating voltage is expediently sinusoidal, but may also adopt other forms, for example sawtooth or square-wave form.

The catalytically active material 6 is deposited 10 on the substrate 4 in the form of clusters. According to the invention, the clusters may have different forms which can be predetermined by the deposition parameters. The substrate 4 which is coated with catalytically active material 6 then forms the 15 catalytic converter.

The direct voltage V_{dc} is preferably at least as great as the deposition potential of the catalytically active material 6 on the substrate 4, particularly 20 preferably at most 50% higher. The precise level of the direct voltage V_{dc} is dependent on the constituents and process conditions employed and may, for example, adopt different values for differently pretreated substrates, although these values do not usually differ greatly 25 from one another. When depositing mixed systems as catalytically active material, it is also possible for the preferred direct voltage V_{dc} to lie below this deposition potential.

30 Stainless steel, particularly Cr-Ni steel 1.4541 [or], CR-Ni steel 1.4571 or Cr-Al steel 1.4767, is used as a particularly suitable substrate. It is expedient for the substrate to be sand-blasted or roughened in some other way, for example chemically, and to undergo 35 alkaline degreasing prior to the coating. This improves the adhesion of the catalytically active material 6 to the substrate 4.

In a preferred embodiment, the alternating voltage

V_{ac} has a maximum voltage swing V_{pp} between minimum and maximum which is lower than the direct voltage V_{dc} , so that overall the sign of the sum voltage between substrate 4 and counterelectrode 3 does not change.

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The current between substrate 4, which serves as the cathode during the deposition, and anode 3 is recorded and, in accordance with Faraday's law, is used as a measure for determining the quantity of 10 catalytically active material 6 deposited, this material being contained in the deposition bath; current contributions which flow for the purpose of building up and breaking down the electrolytic double layer on account of the modulation are expediently 15 eliminated, since they do not originate from the reduction or oxidation of cations or anions.

It is preferable to deposit precious metals in order to produce the catalytic converter. However, it 20 is also possible to deposit mixtures of precious metals. An expedient, inexpensive anode is platinum-coated titanium instead of a standard sacrificial anode made from solid platinum, which can be used to particularly good effect if platinum is to be deposited 25 as catalytically active material. However, other precious metals and also other metals can be deposited in this inventive way.

The frequency and/or the amplitude V_{pp} and/or the 30 voltage offset V_{dc} of the modulated voltage can be adjusted in order to optimize the deposition parameters for the particular system. The values affect both the size of the clusters which are deposited on the metallic cathode and their morphology. Overall, the 35 clusters on the substrate 4 constitute a large active surface area for catalytic reactions. The optimum cluster size can be set in each case for different applications by suitably selecting the deposition parameters and the duration of coating.

It is particularly advantageous for the surface of the substrate 4 which is to be coated to be roughened prior to the coating, for example by pickling or sandblasting. Other methods for increasing the surface roughness are also possible. This is illustrated in Figure 2 with reference to a diagrammatic side view of a coated surface. A substrate 4 has a roughened surface 4.1 on which spherical metal clusters 6.1 are arranged in recesses. The metal clusters 6.1 may also be deposited on the peaks or the flanks of the roughened areas.

The increased surface roughness has the advantage that deposited clusters 6.1 adhere more successfully to the substrate surface, and undesirable combining of the clusters 6.1 is suppressed. A catalytically active layer of individual clusters 6.1 is formed; the layer is preferably not continuous, but rather is formed from isolated clusters 6.1.

The surface roughness is preferably between 0.3 µm and 10 µm, particularly preferably between 0.3 µm and 3 µm. A large active surface area is formed from the finely distributed clusters 6.1. A further advantage is that the increased surface roughness [even] also contributes to increasing the surface area of the substrate 4 and therefore also the chemically active surface area. At the same time, the clusters 6.1 can be very small, so that overall only a small quantity of the expensive catalytically active material 6 has to be deposited, yet at the same time the catalytic converter is distinguished by a high catalytic activity.

The adhesion of the metallic clusters 6.1 to the substrate surface 4.1 is very good. This makes the catalyst layer more resistant to erosion.

A particular advantage over conventional catalyst

layers is that, according to the invention, good heat transfer from the catalyst layer to the substrate 4 is possible, since metallic clusters 6.1 are joined to a metallic substrate 4. By contrast, known, conventional 5 catalyst layers are produced, for example, with supported catalyst materials, in which ceramic support particles are coated with a precious metal. In this case, the heat transfer between catalytically active precious metal and a substrate is significantly worse, 10 since the ceramic particles arranged between them have only a low thermal conductivity. In addition, in a catalytic converter which is produced according to the invention, it is also possible to dispense with standard adhesion promoter layers, which have an 15 additional adverse effect on the heat transfer properties between catalytically active material 6, 6.1 and substrate 4.

A substrate 4 which is coated according to the 20 invention is therefore particularly suitable for use as an oxidation catalytic converter for treating exhaust gases in fuel cell systems. A further expedient application is for various heterogeneously catalysed processes. The catalytic converter according to the 25 invention and the process according to the invention are particularly advantageous in exhaust-gas catalytic converters for vehicles.

Figure 3 shows scanning-electron microscope images 30 of preferred catalytic converters with dendritic platinum clusters (Figures 3a, 3b), and with rhodium clusters which are of substantially dendritic form.

Dendritic platinum clusters are preferably 35 deposited on a stainless steel substrate as a result of a direct voltage V_{dc} of 1.4 volts being superimposed with an alternating voltage V_{ac} with $V_{pp}=0.75$ volt (peak-peak voltage swing) and the modulated voltage being applied between a stainless steel substrate and a

counterelectrode. The frequency of the alternating voltage V_{ac} is 10 Hz. The electrolyte used is platinic acid, in particular hexachloroplatinic acid, with a platinum content of 0.1 g/l. The deposition preferably 5 takes place at room temperature.

The platinum clusters present dendritic growth, and no spherical platinum clusters are observed. The preferred catalytic converter has a high level of 10 activity for hydrogen conversion even in the presence of carbon monoxide, carbon monoxide also being converted with a good yield at the same time.

In the selected system, dendritic platinum 15 clusters are deposited with frequencies of between 5 and 15 Hz and an alternating voltage V_{ac} with a voltage swing V_{pp} of between 0.3-1 volt.

A further preferred catalytic converter is 20 produced by deposition of rhodium on stainless steel, preferably comprising stainless-steel sheet 1.4541 [or], 1.4571 or 1.4767. It is also possible for mixed catalysts of platinum to be deposited in this way or to deposit catalysts comprising mixtures of precious 25 metals and/or catalytically active materials, such as for example PtRh, PtRu, PdPt.

Deposition takes place from a solution of 0.2 g/l of rhodium in 0.1 M H_2SO_4 at room temperature with a 30 direct voltage V_{dc} of 1.4-1.6 volts and a superimposed alternating voltage V_{ac} with $V_{pp}=1$ volt (peak-peak amplitude) and a frequency of 10 Hz. The formation of dendritic growth of the clusters can be improved still further by varying the voltage parameters.

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A catalytic converter of this type has a good activity for methanol. A catalytic converter of this type is therefore particularly suitable for use in fuel cell vehicles operated with methanol, particularly

preferably in catalytic burners.

Figure 4 shows a scanning-electron microscope image of a further preferred catalytic converter with spherical platinum clusters. The deposition takes place using a direct voltage V_{dc} of 1.2-1.4 volts and an alternating voltage V_{ac} with $V_{pp}=0.4$ volt and 100 Hz; the deposition bath otherwise corresponds to that used for Figure 3.

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In this system, an alternating voltage V_{ac} with frequencies of more than 50 Hz, preferably up to 150 Hz, is preferably used for the deposition of spherical platinum clusters. The direct voltage V_{dc} which is applied varies with the substrate pretreatment and, for the deposition of spherical clusters, is substantially equal to or tends to be slightly lower than that used for the deposition of dendritic clusters.

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Figure 5 shows a comparison of scanning-electron microscope images of a catalytic converter with dendritic platinum clusters before (Figure 5a) and after (Figure 5b) a long-term test, in which the catalytic converter was exposed to an H_2/CO mixture at high temperature for more than 200 h. Although exposed to high temperatures of up to $600^\circ C$, the porous or non-cohesive platinum layer as catalyst remains stable; the clusters remain fixed in position and do not converge. The layer which has been deposited in accordance with the invention demonstrates that the clusters in practice do not change before and after long-term use.

Figure 6 shows a comparison of rough (Figure 6a) and smooth (Figure 6b) surface profiles of steel substrates which have been used for the deposition of the platinum. The adhesion of the platinum clusters to the roughened substrate is significantly better than the adhesion to the smooth substrate; the layers are

wipe-resistant, while the layers on an untreated, smooth substrate are not wipe-resistant. The surface roughness is preferably between 0.3 μm and 10 μm , particularly preferably between 0.3 μm and 3 μm .

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The catalytic activity and/or selectivity of the catalytic converter differs depending on the particular form of the clusters. A preferred catalytic converter with spherical platinum clusters converts hydrogen in a substantially selective manner. The catalytic converter is poisoned and has a greatly reduced activity in the presence of carbon monoxide. A catalytic converter of this type is preferably used under carbon monoxide-free conditions.

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By contrast, a preferred catalytic converter with dendritic platinum clusters firstly has a high tolerance to carbon monoxide during the hydrogen conversion and secondly has a high selectivity and high activity both for the hydrogen conversion and for the carbon monoxide conversion.

Figure 7 shows a measurement curve illustrating the hydrogen conversion achieved by a preferred catalytic converter with spherical platinum clusters. The catalytic converter is exposed to an H₂/CO mixture under standard operating conditions. After even a few minutes, the hydrogen conversion in the presence of CO falls to low levels.

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Figure 8 shows a measurement curve illustrating the hydrogen conversion achieved by a preferred catalytic converter with dendritic platinum clusters. In this case too, the catalytic converter is exposed to an H₂/CO mixture under standard operating conditions. However, the measurement curve shows that the conversion of hydrogen and for carbon monoxide remains at substantially constant high levels over more than 200 hours. The conversion can in each case be improved

further, since the operating conditions have not been optimized.

A catalytic converter which has been produced in accordance with the invention is particularly resistant to erosion, and its production can be successfully reproduced. The deposition parameters of the catalytically active material on the substrate can easily be optimized for different materials which are to be deposited by suitably selecting the direct voltage V_{dc} , alternating voltage amplitude V_{pp} and/or frequency. Process control is simple, and the catalytic converter properties can be reproducibly set by simple modifications to the deposition process. The yield of material is good, so that, for example for highly active platinum catalytic converters, relatively small quantities of the precious metal have to be used.

A preferred use for a catalytic converter produced according to the invention is use in a CO-rich environment, in particular in an exhaust-gas cleaning system in a motor vehicle. A further preferred use of a catalytic converter according to the invention is its use in a fuel cell system.